

# Lighting and Grid Integration Research



Pacific Northwest National Laboratory  
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PNNL-SA-142494

# Project Summary

## Timeline

Start date: 10/1/2018 **New Project**

Planned end date: 9/30/2021

## Key Milestones (FY 2019)

1. CLS grid services report 5/31/2019
2. CLS modeling report 8/31/2019

## Budget

### **Total Project \$ to Date:**

- DOE: \$500k
- Cost Share: \$0

### **Total Project \$:**

- DOE: \$1500k
- Cost Share: \$0

## Key Partners

Technology Developers	
End users	
Electric Utilities	
Agencies, Power Authorities	NYSERDA

## Project Goals and Outcomes

The ability of Connected Lighting Systems (CLS) to deliver potential grid services while simultaneously delivering sufficient lighting service and occupant satisfaction has not yet been proven or quantified. This project will quantify and advance the ability of CLS to provide grid services through modeling and simulation, laboratory testing, and field testing. Project results will be disseminated via targeted mechanisms to technology developers, lighting manufacturers, building owners and operators, system integrators, industry standards organizations, and other researchers.

# Team



Michael Poplawski  
EE/SS-Physics/PI  
20/10 years



Michael Brambley  
ME/Control/PI  
28/22 years



Kelly Gordon  
Public Policy/PM  
30/19 years



Yan Chen  
EE-AE/Mod-Sim  
4/4 years



Michael Myer  
LE/Codes-Standards  
14/12 years



Peng Wang  
EE-CS/Mod-Sim  
1/1 years



Abhishek Somani  
Economics/Grid  
8/8 years



David Anderson  
Economics/Grid  
28/24 years



Jianming Lian  
EE/Control-Grid  
10/8 years



Mallikarjuna Vallem  
EE/Power-Grid  
10/6 years

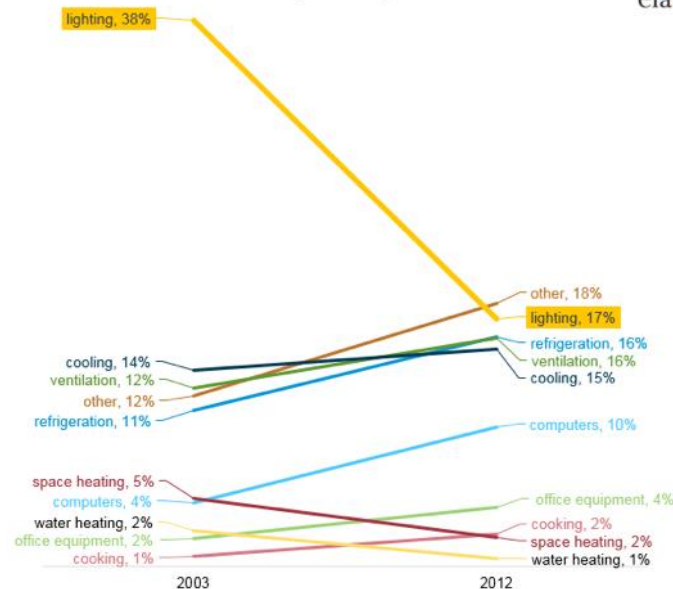
# Challenge







Connected Lighting Systems in GEBs have the potential to deliver improved lighting performance (energy, lighting quality, occupant satisfaction), improved performance of other (e.g., HVAC energy, security) building systems, other valuable data-enabled services, AND grid services. However, at this early stage in their development, their grid service potential is largely not being pursued for many reasons. At or near the top of this list are two key challenges:

1) Lighting systems have not received as much attention from lighting and grid service stakeholders to date as their HVAC counterparts due to perceived limitations. While their portion of building energy consumption is also significant, they typically cannot shift their consumption, and maintaining occupant satisfaction is more dependent on a variety of building and occupant factors.

2) While the financial benefits for GEBs participating in the nascent grid service market are still very much unknown, much uncertainty exists as to whether lighting systems could, even theoretically, provide significant or unique grid services.

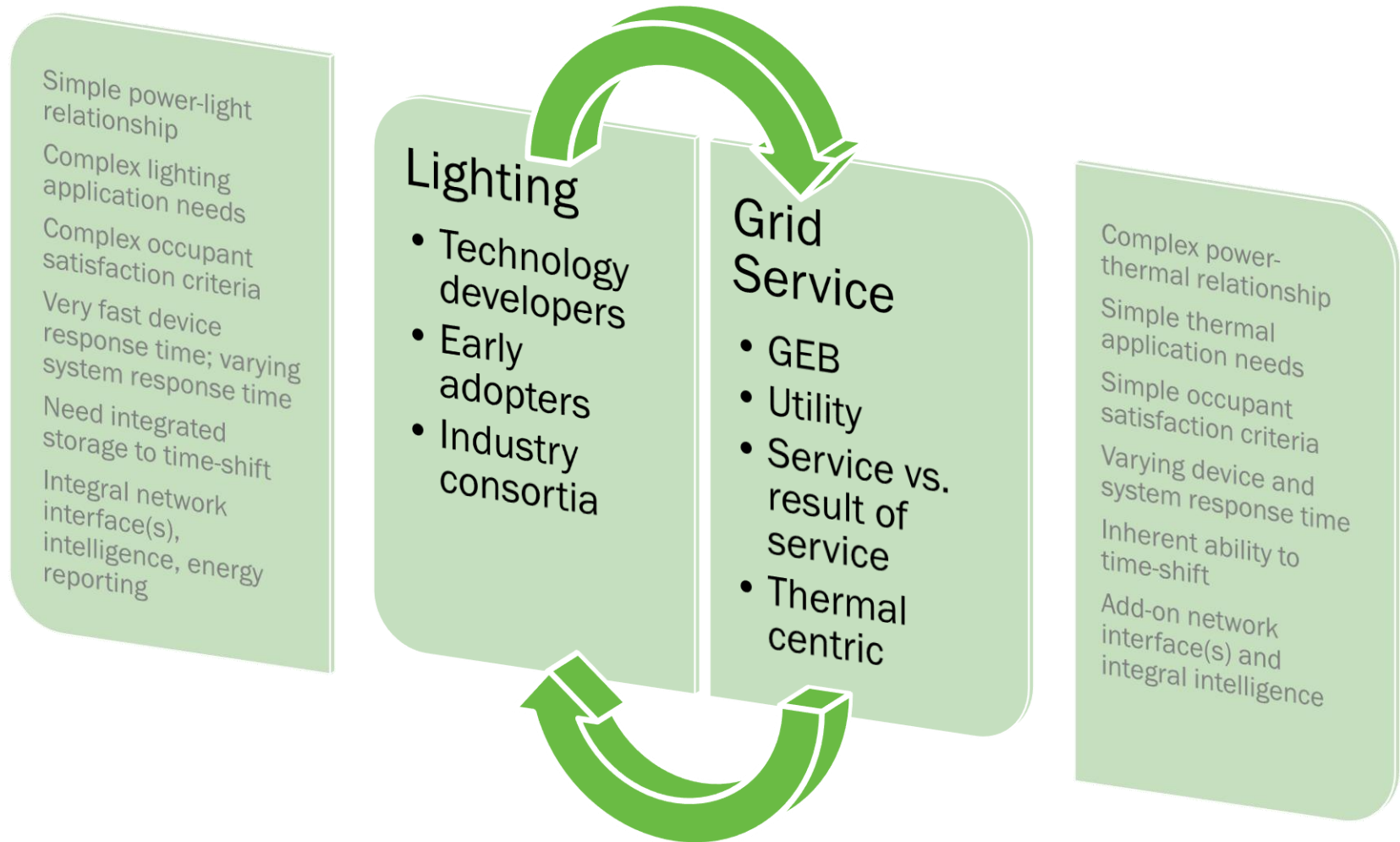
Figure 4: In the commercial sector, lighting is no longer the largest end use as a share of total electricity consumption



	Passive	Active	Connected	EE+DR Additionality
Non-Storage	Daylighting 	LED Lighting 	Lighting Controls 	<b>Optimized Lighting:</b> <ul style="list-style-type: none"> <li>Minimized Energy Consumption</li> <li>High Occupant Comfort</li> <li>Low Ability to Provide Grid Services</li> </ul>
	Phase Change Materials 	H <sub>2</sub> O-Based Thermal Storage 	Controllable Multi-Speed HVAC 	
Storage				<b>Optimized Comfort:</b> <ul style="list-style-type: none"> <li>Minimized Energy Consumption</li> <li>High Occupant Comfort</li> <li>High Ability to Provide Grid Services</li> </ul>

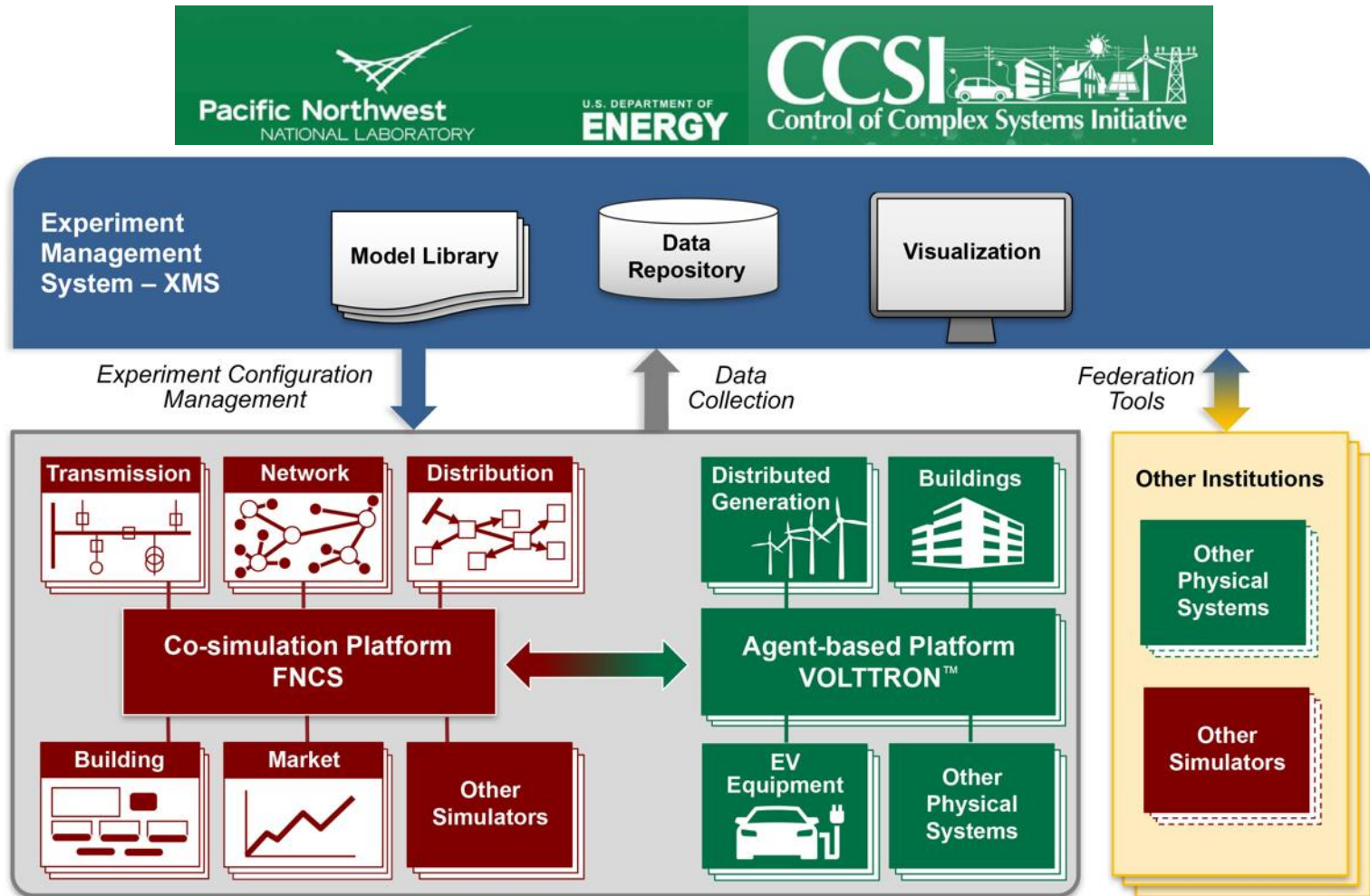


# Approach – Cross stakeholder education



*Goal: Define CLS characteristics that enable grid services, performance metrics key to the delivery of specific services, and methods for quantifying services.*

# Approach – Simulation based analysis



*Goal: Quantify the potential for CLS to provide substantial or novel grid services under a range of building and electric grid operating conditions.*

# Approach – Laboratory & virtual test beds

## Connected Lighting Test Bed



## Early Adopter Deployment(s)



- **Goal: Develop field evaluation plan**
  - Project criteria and, if possible, potential project sites (not pilot studies)
  - Validate laboratory results
  - Characterize stakeholder (owner, operator, occupant, other) satisfaction
- **Goal: Initiate field evaluation, if suitable site identified**



# Impact – Technology development

## Near term

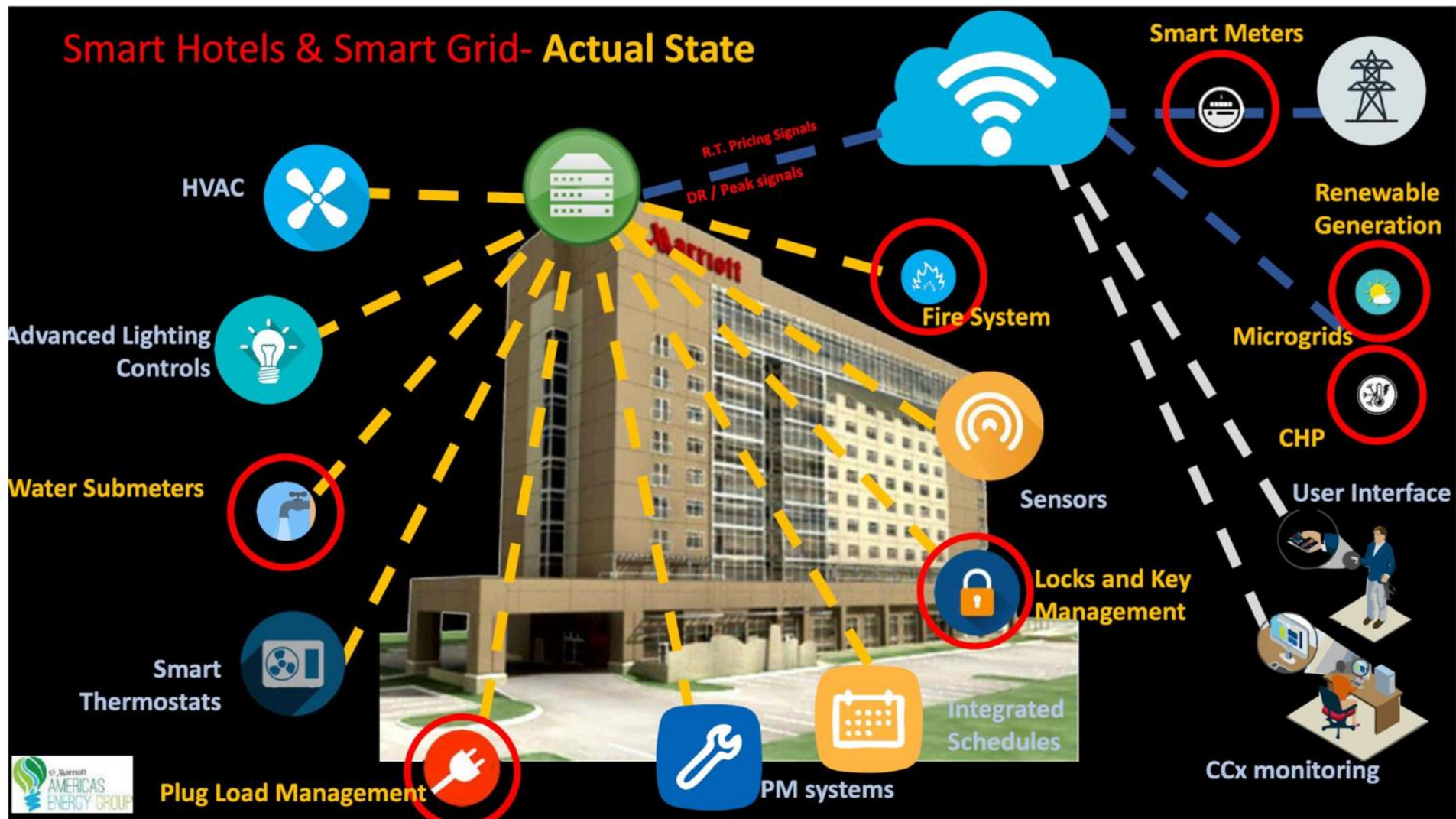
- CLS configurable for providing grid services
  - Grid service type
  - Occupant satisfaction sensitivity
- CLS capable of receiving and interpreting grid service signal
  - API
  - [OpenADR](#), other protocols
- CLS capable of verifying delivery of grid service
  - Energy reporting
  - Accuracy, resolution, latency

## Future term

- CLS with incremental ability to provide grid services via integration of incremental/modular storage
- CLS capable of real-time discernment of occupant satisfaction
  - Current, predictive occupancy
  - Current, predictive task
- CLC capable of incorporating specific occupant needs/preferences into grid-service capability
  - Configurable, occupant opt-in
  - Cybersecurity and privacy



# Impact – Early adopter success



Source: Douglas Rath, Marriott International

# Impact – Industry consensus

## Near term

- Substantial/unique grid service capabilities of CLS
  - Focus for CLS technology developers
  - Design focus for GEB system integrators
- Grid service signaling interoperability with CLS
  - Applicable API resources
  - [OpenAPI Initiative](#) or other

## Future term

- Substantial/unique grid service capabilities of storage-enabled CLS
- Grid service signaling interoperability with CLS
  - Embedded protocol support
  - [OpenADR](#) or other

# Progress – Project coordination

## CLS types

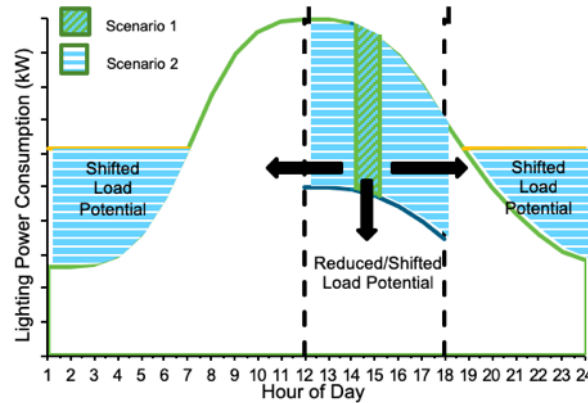
Advanced Adaptive Lighting Control Algorithms

Integrated Batteries

DC LEDs **Luminaires**

Hybrid Sunlight LED Systems

SSL Displays



		Flexibility Purpose	Load Change Characteristics	Flexibility Asset	Technical Requirement	Grid Services		
			Building reduces overall demand	All efficient appliances, HVAC, and other loads	Full response time and no response requirements. Interval data is only needed for M&V purposes	Reduce generation operating cost Reduce Transmission Upgrade Costs Reduce Distribution Upgrade Costs		
Category	Grid Services or Value <sup>3</sup>	Load Change Characteristics	Technical Requirements <sup>4</sup>	Example Technologies				
Peak Shaving	<ul style="list-style-type: none"><li>Avoided Generation Capacity Costs</li><li>Avoided Transmission and Distribution Upgrade Costs</li></ul>	Building reduces demand during the generation balancing area's annual peak demand period(s) or during grid emergencies (e.g., generation asset trips offline). This can be achieved via: <ul style="list-style-type: none"><li>Load <b>Shifting</b> for forecasted (non-emergency) peaks</li><li>Load <b>Shedding</b> for emergency events or for loads that cannot be shifted</li></ul>	<ul style="list-style-type: none"><li>Full response time: 1-4 hrs<sup>5</sup></li><li>Dispatch duration typically 2-4 hrs</li></ul>	<ul style="list-style-type: none"><li>Thermostat setpoints</li><li><b>Surge-enabled Connected Lighting</b></li><li>Thermal storage</li><li>Smart appliances and water heaters</li><li>Batteries</li></ul>	start to	Full response time: 1-4 hours to	Reduce generation costs Reduce transmission	
	<ul style="list-style-type: none"><li>Frequency Regulation: regulation in response to an ancillary service market - fast response - for balancing electricity supply and demand to maintain a 60 Hz frequency</li></ul>	Building automatically modulates its power demand in response to a signal (typically every 2-10 seconds) from the grid operator during the dispatch period. Also known as load <b>Shifting</b>	<ul style="list-style-type: none"><li>Full response time: &lt;1 min</li><li>Must be able to receive automatic generation control signal (AGC)</li><li>Advanced telemetry is required for output signal transmission to grid operator</li></ul>	<ul style="list-style-type: none"><li>Batteries</li><li>VFD motors</li><li>Connected water heaters</li><li>Solar inverters</li><li><b>Connected Lighting</b></li></ul>	With notice of 5 minutes to 1 hour, reduce load for a period of 1-4 hours to reduce peak demand		<ul style="list-style-type: none"><li>All technologies providing energy efficiency</li></ul>	<ul style="list-style-type: none"><li>Reduce generation cost</li><li>Reduce transmission congestion</li><li>Reduce distribution congestion</li><li>Reduce generation costs</li><li>Reduce transmission congestion</li><li>Reduce distribution congestion</li><li>Provide ramping reserves</li><li>Provide contingency reserves</li></ul>
Regulation	<ul style="list-style-type: none"><li>Distribution Voltage and Reactive Power Support; regulation in response to an ancillary service market - fast response</li></ul>	Building automatically modulates its reactive power draw or supply based on a grid operator's signal (typically every 2-10 seconds) to maintain distribution system voltage during the dispatch period. This ancillary service is less applicable to most building equipment than other services.	<ul style="list-style-type: none"><li>Full response time: sub-seconds to seconds</li><li>Need autonomous sensors within DER inverters or grid feed inverters that can also modulate power quality using grid power only.<sup>6</sup></li><li>Advanced telemetry is required for output signal transmission to grid operator</li></ul>	<ul style="list-style-type: none"><li>Batteries</li><li>Thermal storage</li><li>Refrigeration setpoints</li><li>Batteries</li><li><b>Surge-enabled Connected Lighting</b></li></ul>	With notice of 24-36 hours, shift load away from peak periods to off-peak periods		<ul style="list-style-type: none"><li>Thermal mass</li><li>Thermal storage</li><li>Refrigeration setpoints</li><li>Batteries</li><li><b>Surge-enabled Connected Lighting</b></li></ul>	<ul style="list-style-type: none"><li>Improve utilization of low-cost generation</li><li>Reduce transmission costs</li><li>Reduce generation costs</li><li>Reduce distribution congestion</li><li>Reduce distribution congestion</li><li>Provide ramping reserves</li></ul>
					With notice of 4 seconds, modulate load to follow a curve		<ul style="list-style-type: none"><li><b>Connected Lighting</b></li><li>IT equipment</li><li>VFD motors</li><li>Batteries</li></ul>	<ul style="list-style-type: none"><li>Support frequency regulation</li></ul>



Energy Technologies Area

## Framework & Method to Define Flexible Loads in Buildings to Integrate as a Dynamic & Predictable Grid Resource

Peter Schwartz (PI), Mary Ann Piette (Co-PI)

Jingjing Liu (Technical Lead)

DOE 2018 National Lab Call DE-LC-000L048

Topic 8 – Grid Service Map & Initial Example Metrics

2/4/19



# Progress – Consensus grid services

## GEB framework (draft)

1. Reduce generation operating costs
2. Reduce generation capacity costs
3. Provide contingency reserves (non-spinning)
4. Provide distribution voltage support
5. Provide frequency regulation
6. (Provide ramping)
7. Reduce transmission upgrade costs
8. Reduce distribution upgrade costs

## Project proposal (Focused on limited set)

1. Energy service
2. Peak demand limiting
3. Regulation
4. Frequency response

## PNNL cross-project analysis (in-progress)

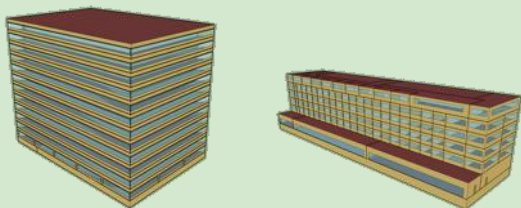
1. Long-term Capacity or Resource Adequacy
2. Regulation Up/Down
3. Operating Reserve
  - a) Spinning
  - b) Non-spinning
4. Other Market Products and Services
  - a) Flexible Ramping
  - b) Voltage Support
  - c) Fast Frequency and primary frequency response
  - d) Black Start
  - e) Distributed system services

# Progress – Lighting model parameters

## Lighting profile (Space types)

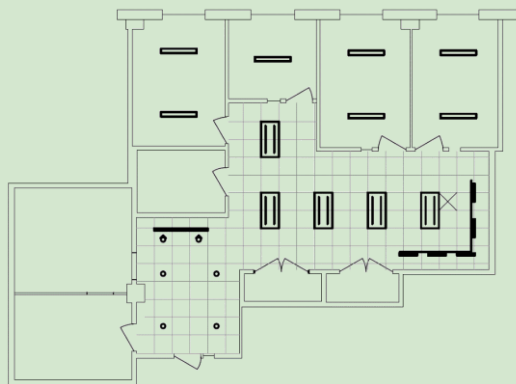
DOE commercial prototype building models

- Small, Medium, Large Office
- Standalone Retail
- Strip Mall
- Primary, Secondary School
- Outpatient Healthcare, Hospital
- Small, Large Hotel
- Warehouse
- Quick-service, Full-service Restaurant
- Mid-rise, High-rise Apartment



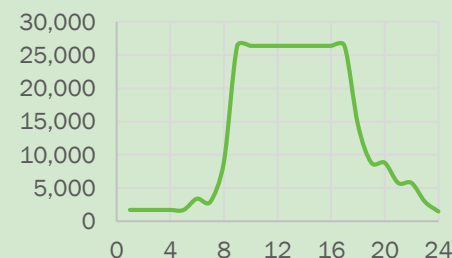
## Lighting load (Power)

- ASHRAE 90.1-2019 lighting power density (LPD) values
- Up to four luminaire types per space
- ASHRAE 90.1 Lighting Subcommittee luminaire type power data



## Lighting schedule (Hours-of-use)

- ASHRAE 90.1-2009 Advanced Energy Design Guides, Technical Support Documents
- ASHRAE 90.1-2004 User's Manual Section G
- ASHRAE 90.1-1989 Section 13 Energy Cost Budget Method
- Apartment study (Gowri 2007)



# Progress – Lighting model parameters

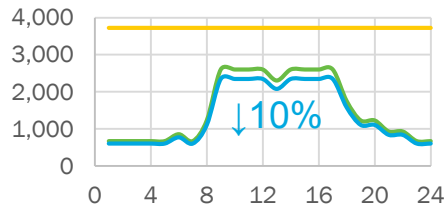
- Nominal illumination (power, per hour of day)
- Maximum illumination (power, per hour of day)
- Minimum illumination (power, per hour of day)
- Illumination (power) ramping (up/down) rate
- Delay (grid service signal → onset of service)
- ~~Response time (initiation of service → full activation of service)~~
- ~~Duration of service~~



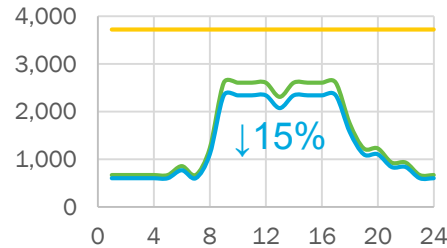
# Progress – Lighting parameters

Small Office Building  
(5,500 square feet)

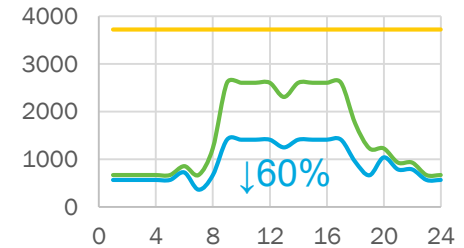
ASHRAE 189.1-2014  
Model



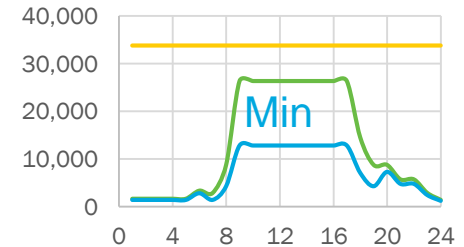
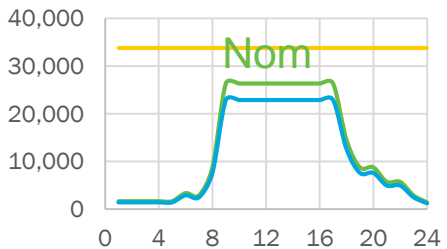
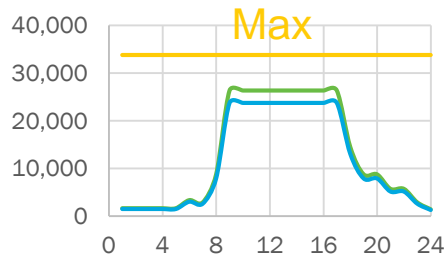
Title 24-2019 Model



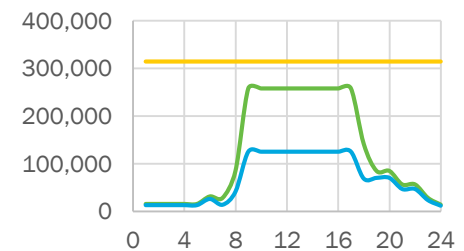
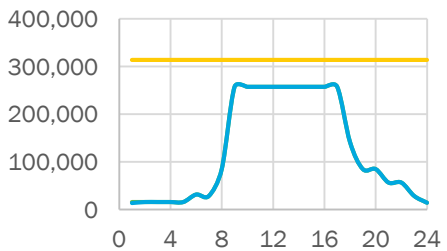
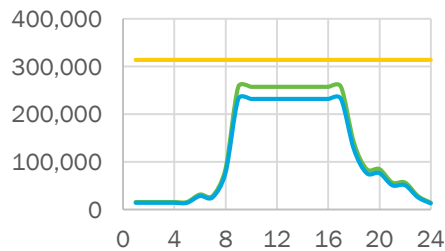
WELL Daylit Model



Medium Office Building  
(53,600 square feet)



Large Office Building  
(500,000 square feet)



# Stakeholder Engagement – PAG (Project Advisory Group)

- Approximately six representatives
  - External stakeholders from the lighting, building, and electric-grid industries with the knowledge and background that enable them to judge market relevance of the project work
  - Assess the marketplace relevance of the project work, and make recommendations for increasing the market relevance
- Quarterly teleconference meetings
  - Updates on current project activities and approaches, preliminary research findings, upcoming planned activities, and summaries of other stakeholder interactions (e.g., webinars, presentations, reviewer feedback on papers)
  - DOE management invited
- Yearly DOE briefings
  - Summarizes teleconference meetings and the anticipated market relevance of the research as of that time
  - Include notable feedback from stakeholders responding to presentations, research reports, journal articles, and other outreach activities

# Stakeholder Engagement – PAG recruitment

Technology developers (TBD): Lighting, Storage, Other?



End users (TBD)



Electric utilities (TBD): Large/typical, forward-looking, medium/small, municipal, cooperative



Electric utility agencies



Power Authorities (TBD)





# Remaining Project Work – Work Plan

Task	Description	Due Date
1	Characterize CLS Opportunity for Providing Grid Services	M01-M6
2	Develop CLS Models and Integrate into Existing Co-Simulation Platform	M06-M12
3	Quantify CLS Potential Contributions to Grid Services Using Simulations 1) Prepare the co-simulation environment 2) Develop Simulation Test Plans 3) Perform Simulations and Analyze Results	M06-M30
4	Evaluate CLS Ability to Provide Grid Services in a Laboratory Environment	M06-M30
5	Develop Plans for Field Evaluation of CLS Ability to Provide Grid Services	M30-M36
6	Externally Validate Marketplace Relevance	M01-M36

# Remaining Project Work – Key Milestones

	Task	Description	Due Date
FY19	1	Complete report characterizing CLS opportunity to provide grid services	3/2019
	2	Complete report on CLS models, integration into co-simulation platform	8/2019
	6	Complete DOE briefing on external validation of marketplace relevance	9/2019
FY20	3	Complete report on grid services provided only by CLS based on building-grid simulation results	3/2020
	3	Complete report on grid services provided by coordinated CLS and HVAC based on building-grid simulation results	8/2020
	6	Complete DOE briefing on external validation of marketplace relevance	9/2020
FY21	3	Complete report on grid services provided by coordinated CLS, storage-enabled CLS, and HVAC based on building-grid simulation results	2/2021
	4	Complete report on laboratory testing results	5/2021
	5	Complete report on field-testing plan	8/2021
	6	Complete DOE briefing on external validation of marketplace relevance	9/2021

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# Thank You

Pacific Northwest National Laboratory

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# REFERENCE SLIDES

# Project Budget

**Project Budget:** New project starting in FY 2019.

**Variances:** Lower than anticipated spending in first half of FY; will increase in Q3 and Q4 FY19

**Cost to Date:** as of March 2019 month end: \$62k cumulative cost to date

**Additional Funding:** None

## Budget History

FY 2018 (past)		FY 2019 (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
N/A	None	\$500k	\$0k	\$1000k	TBD



# Project Plan and Schedule

Project Schedule																			
Project Start: 10/1/2018								Completed Work											
Projected End: 9/30/2021								Active Task (in progress work)											
								◆ Milestone/Deliverable (Originally planned) use for missed											
								◆ Milestone/Deliverable (Actual) use when met on time											
								FY19			FY20			FY21					
								Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Characterization of Connected Lighting Systems Potential to Provide Grid Services																			
Past Work																			
Characterizing CLS opportunity to provide grid services - report outline in slide form									◆										
Characterizing CLS opportunity to provide grid services - complete report										◆									
Current/Future Work																			
Complete report on CLS models, integration into co-simulation platform											◆								
Complete DOE briefing on external validation of marketplace relevance												◆							
Complete report on grid services provided only by CLS based on building-grid simulation results													◆						
Complete report on grid services provided by coordinated CLS and HVAC based on building-grid simulation results														◆					
Complete DOE briefing on external validation of marketplace relevance															◆				
Complete report on grid services provided by coordinated CLS, storage-enabled CLS, and HVAC based on building-grid simulation results																◆			
Complete report on laboratory testing results																	◆		
Complete report on field testing plan																		◆	
Complete DOE briefing on external validation of marketplace relevance																			